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The calculation of electronic masking for use in telecine

No. 1972/24

Research Department, Engineering Division
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RESEARCH DEPARTMENT

THE CALCULATION OF ELECTRONIC MASKING FOR USE IN TELECINE

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(PH-88)

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THE CALCULATION OF ELECTRONIC MASKING FOR USE IN TELECINE

Summary

Electronic masking[1] *provides a means whereby some of the defects in the reproduction of a scene by colour motion-picture photography may be compensated electronically when the film is scanned by television. Prior to the use of electronic masking, television film scanners could do no more than attempt to give a reproduction of the scene similar to that produced by optical projections, and the results were usually inferior to the pictures produced by television cameras.*

This report describes a means of calculating the electronic masking required to ensure that the original film record of a scene is used to its best advantage in television presentation.

1. Introduction

Two quite different approaches may be made towards the generation of television pictures from colour motion-picture film. The first, and perhaps the most obvious, is to attempt to reproduce, on the television screen, the picture which would be obtained by optically projecting the film; this result could be obtained by using, in the telecine, colour analysis characteristics broadly similar to those used in a colour camera. The second approach is to regard the colour film simply as a recording medium in which the scene information is already resolved into superimposed colour-separation images (e.g. red, green and blue) by the analysis characteristics of the negative film, and to generate corresponding colour-separation signals which are suitable for the colour display and are as free as possible from unwanted cross coupling.

By adopting the second approach, and by employing electronic masking in the process of obtaining the colour-separation signals relating to the colour-separation dye images, certain advantages may be gained with regard to the final reproduced picture.

2. The picture presented by optical projection

2.1. The subtractive colour process

Colour film presented by optical projection is a subtractive colour process; the dyes in the positive film absorb light from the projector, over certain regions of the visible picture, causing the remaining light to pass to the projection screen. In practice this process causes distortions to the reproduction in respect of saturation and luminance. The reasons may be found from a study of the dye characteristics. Three coloured dyes are employed, which together control the whole spectrum of light reaching the projection screen; separately they are intended to control those sections of the spectrum corresponding to the primary colours, red, green and blue. From a glance at the spectral density characteristics of typical dyes, shown in Fig. 1, it can be seen that each dye has some absorption over most, if not the whole, of the visible region, and it is these characteristics which cause errors in the projected picture. This can be explained in the following way.

Suppose it is required to reproduce a very bright and saturated blue on the projection screen. In order to obtain high saturation, all the red and green light from the projector must be absorbed, which calls for high cyan and magenta dye-densities in the film. From examination of the spectral characteristics of the film dyes (Fig. 1) it will be seen that, under these conditions, absorption of blue light also takes place and, in consequence, the intensity of the blue light reaching the screen is reduced. This causes a reduction in both the luminance and saturation of the reproduced blue.

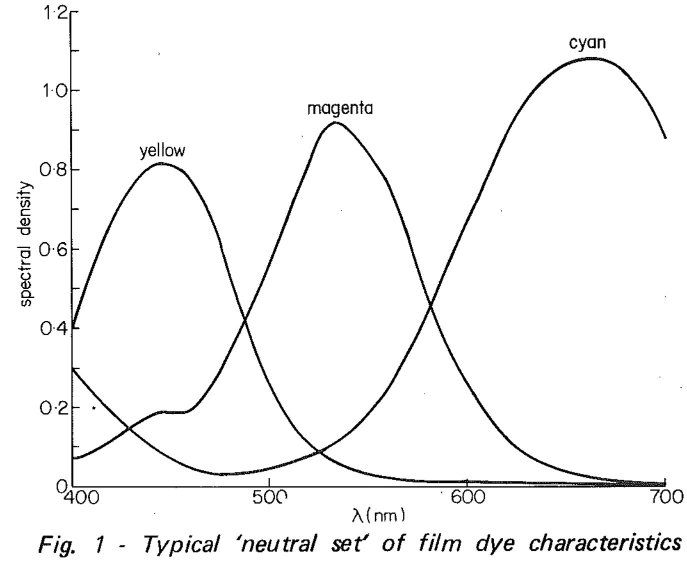

Fig. 1 - Typical 'neutral set' of film dye characteristics

2.2. Corrections in the film process for film-dye deficiencies

The film manufacturer attempts to offset the dye deficiencies by raising gamma, that is, by shaping the transfer characteristic of the film so as to expand the contrast. This enhances saturation but the consequent distortion of the brightness scale results in a reduced amount of the scene contrast-range being displayed since there is limited contrast attainable in the film, which is further restricted by projection. The overall result in the cinema is, however, acceptable as is evident by the success of colour film in the motion-picture industry. Other measures employed to offset the film deficiencies, such as dye making-techniques – which also enhance saturation, may be used in some special films such as colour negative film.

3. An alternative approach to the reproduction of film in television

Motion-picture colour film may be regarded as a three-colour channel recording of the original scene; the fact that the subject of the recording is visible as a colour picture is, in this context, incidental. Knowing the parameters of the film record it is possible to scan the film in a telecine and produce separation signals which, in principle, are proportional to the original light stimuli from the scene, which exposed the negative film in the film camera. By this means it is possible to obtain a television reproduction of the original scene which is more accurate than that achieved with optical presentation.

3.1. The film 'recording' process

The production of a colour photograph of a scene is initiated in the film camera in the same way as the production of television pictures in a colour television camera. The light from the scene enters the camera lens and produces an image of the scene on the three sensitive layers of the negative film; the image is separated by filters into red, green and blue separation images and these are separately recorded; at this point the similarity between a colour camera and a colour film ends. After processing, three dyes are produced in the film whose densities are related to the intensities of the red, green and blue components of the light falling on the film. These dyes are cyan, magenta and yellow in colour and their densities may be considered as records of the red, green and blue separation images of the scene.

When the film is subsequently printed, the red component of the light reaching the print film is controlled in brightness by the concentration of the cyan dye (since it absorbs red light), the green light is controlled by the magenta dye and the blue light is controlled by the yellow dye. The picture formed after processing the print film is therefore a positive picture in which the extent to which cyan due is absent represents the positive red separation-image of the scene; corresponding arguments apply for the magenta dye (green separation-image) and the yellow dye (blue separation-image).

If a telecine machine were able to produce three electrical signals each independently controlled according to the extent to which each film dye is absent in the print, these signals would then be similar to those from a colour camera viewing the original scene. The remainder of this report is mainly devoted to the application of electrical matrixing techniques in the telecine process, as a means for achieving these requirements.

4. Film scanning by telecine

4.1. The photomultiplier output signals

The photomultipliers in a telecine provide signal currents in proportion to the total light energy received. The light from the flying spot tube is focused on to the film plane, and light passing through the film is split into red, green and blue components which are collected by separate photomultipliers.

With no film in the telecine gate the gain of each photomultiplier is adjusted so that white level produces a unit signal level

p.e.c. white-level signal (open gate):

$$E_{OG} = \mathrm{K}\int_{\lambda_1}^{\lambda_2} T_{\mathrm{S}}(\lambda)\,\mathrm{d}\lambda \qquad (1)$$

λ_1 and λ_2 are the limits of the spectrum of light received by the photomultiplier and $T_{\mathrm{S}}(\lambda)$ is the effective transmission of the telecine analysis at wavelength (λ) for the particular channel (red, green or blue) under consideration. The telecine analysis characteristic is derived by multiplying together the spectral characteristics of all optical components in the particular light path, including filters, the spectrum of the light emitted from the flying spot tube, and the spectral response of the photomultiplier.

The constant K is related to the photomultiplier gain and permits the normalisation to unit signal level for white so that

for $E_{OG} = 1$

$$\mathrm{K} = \frac{1}{\int_{\lambda_1}^{\lambda_2} T_{\mathrm{S}}(\lambda)\,\mathrm{d}\lambda} \qquad (2)$$

When a film is placed in the telecine gate it absorbs some of the light falling on it and the photomultiplier signal is reduced from the open-gate level to a level linearly dependent upon the spectral transmission of the film over the relevant wavelength range.

The relative p.e.c. signal with film in the gate is therefore

$$E_{\mathrm{f}} = \frac{\mathrm{K}\int_{\lambda_1}^{\lambda_2} T_{\mathrm{S}}(\lambda)\,.\,T_{\mathrm{f}}(\lambda)\,\mathrm{d}\lambda}{\mathrm{K}\int_{\lambda_1}^{\lambda_2} T_{\mathrm{S}}(\lambda)\,\mathrm{d}\lambda} \qquad (3)$$

where $T_f(\lambda)$ is the transmission of the film at wavelength λ

4.2. Narrow band analysis

If the band of wavelength from λ_1 to λ_2 is very narrow and approximates to a spectral line then

$$E_f = \frac{KT_S(\lambda)\,T_f(\lambda)}{KT_S(\lambda)} = T_f(\lambda) \qquad (4)$$

The spectral transmission characteristic of a film $T_f(\lambda)$ is the product of the individual spectral transmission characteristics of the cyan, magenta and yellow dyes ($T_C(\lambda)$, $T_M(\lambda)$, $T_Y(\lambda)$).

Hence for a narrow band of wavelengths, from (4)

$$E_f = T_C(\lambda)\,.\,T_M(\lambda)\,.\,T_Y(\lambda) \qquad (5)$$

Now the density of a film D is related to its transmission T by the formula

$$D = \log_{10}\frac{1}{T}$$

so that Equation (5) can be re-written

$$E_f = 10^{-[D_C(\lambda) + D_M(\lambda) + D_Y(\lambda)]} \qquad (6)$$

where $D_C(\lambda)$, $D_M(\lambda)$ and $D_Y(\lambda)$ are the spectral dye densities at wavelength λ.

Thus by taking the logarithm of the p.e.c. output signal a further signal related to the effective dye densities may be obtained

$$-\log_{10}E_f = [D_C(\lambda) + D_M(\lambda) + D_Y(\lambda)] \qquad (7)$$

The density of each dye, at wavelength λ, ($D_C(\lambda)$, $D_M(\lambda)$, $D_Y(\lambda)$) may be related by a coefficient to its equivalent neutral density

$$D_C(\lambda) = a_1 D_C$$
$$D_M(\lambda) = a_2 D_M$$
$$D_Y(\lambda) = a_3 D_Y$$

Coefficients a_1, a_2, a_3 are constant for a given wavelength λ and for given spectral characteristics of dye densities.

Equation (7) now becomes

$$-\log_{10}E_f = a_1 D_C + a_2 D_M + a_3 D_Y \qquad (8)$$

In a telecine three such signals are obtained, one for each primary colour, and the three corresponding expressions for the signals from the red, green and blue channels may be written in the form of a matrix equation

$$\begin{bmatrix} -\log R \\ -\log G \\ -\log B \end{bmatrix} = \begin{bmatrix} a_{1R} & a_{2R} & a_{3R} \\ a_{1G} & a_{2G} & a_{3G} \\ a_{1B} & a_{2B} & a_{3B} \end{bmatrix} \begin{bmatrix} D_C \\ D_M \\ D_Y \end{bmatrix} \qquad (9)$$

a_{1R}, a_{2R}, a_{3R} are coefficients relating density at wavelength λ_R to equivalent neutral densities D_C, D_M, D_Y.

a_{1G}, a_{2G}, a_{3G} are coefficients relating density at wavelength λ_G to equivalent neutral densities D_C, D_M, D_Y.

a_{1B}, a_{2B}, a_{3B} are coefficients relating density at wavelength λ_B to equivalent neutral densities D_C, D_M, D_Y.

λ_R, λ_G, λ_B are the analysis wavelengths for the red, green and blue channels of the telecine.

Once this matrix is known the inverse matrix can be calculated and used to form primary analysis signals (proportional to D_C, D_M and D_Y) from the signals representing the logarithms of the photomultiplier signals.

A graphical interpretation of Equation (9) is shown in Fig. 2 for a spectral line analysis in each channel of the telecine.

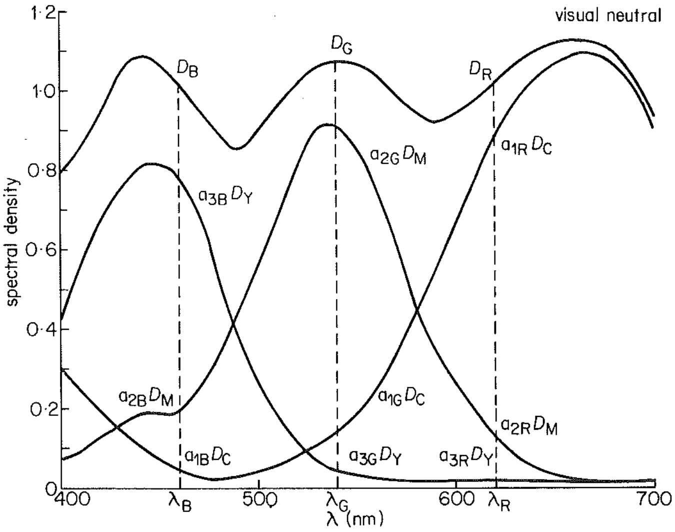

Fig. 2 - Typical 'neutral set' of film dyes with spectral line analysis

4.3. Non-narrow band analysis

In a practical telecine each channel may, for signal-to-noise reasons, have an analysis-wavelength range ($\lambda_1 \rightarrow \lambda_2$) which is relatively large and the theory for narrow band analysis then no longer applies. In order to achieve a solution, certain approximations have to be made, and it will be shown that for practical purposes a treatment similar to that for narrow band analysis may be adopted. (The accuracy of the approximations can be verified by computer calculations on a typical practical system; see Section 5.)

As already stated, the spectral transmission characteristic of a film $T_f(\lambda)$ is the product of the individual spectral transmission characteristics of the cyan, magenta and yellow dyes.

From Equation (3):—

$$E_f = \frac{\int_{\lambda_1}^{\lambda_2} T_S(\lambda) \,.\, T_C(\lambda) \,.\, T_M(\lambda) \,.\, T_Y(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \qquad (10)$$

Consider also another expression

$$E_f = \frac{\int_{\lambda_1}^{\lambda_2} T_C(\lambda)\, T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \,.\, \frac{\int_{\lambda_1}^{\lambda_2} T_M(\lambda)\, T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \,.\, \frac{\int_{\lambda_1}^{\lambda_2} T_Y(\lambda)\, T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \qquad (11)$$

In order to achieve the required result (an approximation to narrow band analysis) it is necessary to show that these two expressions for E_f give approximately the same answer. We can do this by showing that both expressions are approximately equal to a third expression.

If we assume that the transmission of each film dye (T_C, T_M, T_Y) is constant across the analysis passband ($\lambda_1 \rightarrow \lambda_2$) (or varies only slowly), the transmission of each dye as a function of wavelength can be replaced in the above equations by a 'mean' value. Let these 'mean' values be $\overline{T}_C$, $\overline{T}_M$ and $\overline{T}_Y$ for the cyan, magenta and yellow dyes respectively. Since these values are now constants they may be taken outside the integral and further simplifications become possible.

Equation (10) becomes:—

$$E_f = \frac{\overline{T}_C \,.\, \overline{T}_M \,.\, \overline{T}_Y \int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} = \overline{T}_C \,.\, \overline{T}_M \,.\, \overline{T}_Y \qquad (12)$$

and Equation (11) becomes:—

$$E_f = \frac{\overline{T}_C \int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \,.\, \frac{\overline{T}_M \int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \,.\, \frac{\overline{T}_Y \int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda}$$

$$= \overline{T}_C \,.\, \overline{T}_M \,.\, \overline{T}_Y$$

Since this result is identical to Equation (12), Equations (10) and (11) are equivalent if the transmission of each dye varies sufficiently slowly over the analysis passband (i.e. is effectively a constant value); this is approximately true for practical telecine analyses. Moreover, the performance of the final dye density analysis, using masking matrix values calculated on this assumption, can be checked for accuracy; the primary analysis signals which result for various combinations of film dyes can be calculated and compared with the ideal values. The results of such a calculation appear in Section 6.

Comparison of Equations (11) and (12) indicates the method which is used to evaluate the 'mean' values $\overline{T}_C$, $\overline{T}_M$ and $\overline{T}_Y$.

$$\overline{T}_C = .\frac{\int_{\lambda_1}^{\lambda_2} T_C(\lambda) \,.\, T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \qquad (13)$$

$$\overline{T}_M = .\frac{\int_{\lambda_1}^{\lambda_2} T_M(\lambda) \,.\, T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \qquad (14)$$

$$\overline{T}_Y = .\frac{\int_{\lambda_1}^{\lambda_2} T_Y(\lambda) \,.\, T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \qquad (15)$$

This method takes the analysis passband into account within the integral and the limits of the integral (λ_1 and λ_2) may therefore be extended to the limits of the visible spectrum.

Since Equation (12) is equivalent to Equation (5), once the values of $\overline{T}_C$, $\overline{T}_M$ and $\overline{T}_Y$ are known the remainder of the calculation is similar to that for narrow band analysis.

Since $$D = \log_{10} \frac{1}{T}$$

from Equation (12)

$$E_f = 10^{-[\overline{D}_C + \overline{D}_M + \overline{D}_Y]} \qquad (16)$$

where $\overline{D}_C$, $\overline{D}_M$ and $\overline{D}_Y$ are densities equivalent to transmission values $\overline{T}_C$, $\overline{T}_M$ and $\overline{T}_Y$.

$$-\log_{10} E_f = \overline{D}_C + \overline{D}_M + \overline{D}_Y \qquad (17)$$

and if coefficients a_1, a_2, a_3 relate the mean density values $\overline{D}_C$, $\overline{D}_M$ and $\overline{D}_Y$ to the equivalent neutral density of the appropriate dye

$$\overline{D}_C = a_1 D_C$$
$$\overline{D}_M = a_2 D_M$$
$$\overline{D}_Y = a_3 D_Y$$

Then we have Equation (8)

$$-\log_{10} E_f = a_1 D_C + a_2 D_M + a_3 D_Y$$

with coefficient values given by:–

$$a_1 = \frac{D_C}{\overline{D}_C} = \frac{D_C}{\log_{10} \frac{1}{\overline{T}_C}} = \frac{D_C}{\log_{10} \left[\dfrac{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_C(\lambda) \,.\, T_S(\lambda)\, d\lambda} \right]} \qquad (18)$$

$$a_2 = \frac{D_M}{\log_{10} \left[\dfrac{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_M(\lambda) \,.\, T_S(\lambda)\, d\lambda} \right]} \qquad (19)$$

$$a_3 = \frac{D_Y}{\log_{10} \left[\dfrac{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_Y(\lambda) \,.\, T_S(\lambda)\, d\lambda} \right]} \qquad (20)$$

Evaluating values of a_1, a_2 and a_3 for each channel of the telecine in turn will give the complete matrix relationship which, when the matrix is inverted, will give masking matrix values to provide the required primary analysis signals.

As in Equation (9)

$$\begin{bmatrix} -\log R \\ -\log G \\ -\log B \end{bmatrix} = \begin{bmatrix} a_{1R} & a_{2R} & a_{3R} \\ a_{1G} & a_{2G} & a_{3G} \\ a_{1B} & a_{2B} & a_{3B} \end{bmatrix} \begin{bmatrix} D_C \\ D_M \\ D_Y \end{bmatrix} = A \begin{bmatrix} D_C \\ D_M \\ D_Y \end{bmatrix} \qquad (21)$$

$$\begin{bmatrix} D_C \\ D_M \\ D_Y \end{bmatrix} = A^{-1} \begin{bmatrix} -\log R \\ -\log G \\ -\log B \end{bmatrix} \qquad (22)$$

4.4. Equivalent neutral density

In order for a film to produce a neutral grey a certain relative combination of film dyes is required. The quantity of each dye may not be the same since the controlling factor is that, over the visible band, equal or near equal absorption must take place. As can be seen from Fig. 1 the amount of yellow and the amount of cyan dyes required is very different, due to the unwanted absorption by the dyes. If electrical signals are produced, proportional to the quantity of dye, then, for a neutral scene, they would not be equal. In television, equal electrical signals are required for neutral colours and some normalisation is required:

If R, G and B are the required television linear signals then

$$-\log R_1 = x_1 D_C$$
$$-\log G_1 = x_2 D_M$$
$$-\log B_1 = x_3 D_Y$$

where x_1, x_2 and x_3 are normalising constants. From Equation (21) substituting for D_C, D_M and D_Y

$$\begin{bmatrix} -\log R \\ -\log G \\ -\log B \end{bmatrix} = A \begin{bmatrix} -\dfrac{\log R_1}{x_1} \\ -\dfrac{\log G_1}{x_2} \\ -\dfrac{\log B_1}{x_3} \end{bmatrix}$$

Incorporating coefficients x_1, x_2 and x_3 into the matrix and then inverting we have

$$\begin{bmatrix} -\log R_1 \\ -\log G_1 \\ -\log B_1 \end{bmatrix} = B \begin{bmatrix} -\log R \\ -\log G \\ -\log B \end{bmatrix} \qquad (22)$$

4.5. Masking for negative colour film

There are two types of colour negative film which are likely to be used in telecine operation. One is a negative film which contains photographic masking employing further coloured dyes in addition to the three dyes normally encountered, and the other is a film in which only the three basic colouring dyes are present. For negative films which do not employ photographic masking, the process of calculating the masking matrix is similar to that employed for positive film already described, with one exception. The gammas of the three dyes in the negative film may not be identical, in which case the normalising coefficients cannot be calculated from the dye spectral characteristics. The coefficients may be found by measurement of the linear telecine photomultiplier signals when a grey-scale, photographed on the negative film in question, is placed in the telecine. Graphs are drawn of $\log_{10}$ (scene brightness) and $\log_{10}$ (photomultiplier signal) whose slopes are measured. The normalising coefficient is then found by dividing the slope of the graphs into the nominal gamma of the film.

$$\text{slope} = \frac{\text{log (scene brightness)}}{\text{log (p.e.c. output)}} = \gamma$$

$$\text{Normalising coefficient} \quad = \frac{\gamma_n}{\gamma}$$

where γ_n = nominal gamma of the colour negative.

Figures are found for the red, green and blue channels of the telecine and are used in the calculation of the masking matrix to effect the correct reproduction of a grey-scale in respect of gamma and gamma tracking.

Photographic masking often employed in colour negative films provides some degree of compensation for unwanted dye absorptions in the process of printing the negative on to the positive print stock. It is designed solely for this purpose and it would be most unlikely also to provide the necessary masking when the film is used in a telecine. It is usual to employ two extra dyes in the film for the purpose of masking, one being yellow and coupled to the magenta dye, the other being orange and coupled to the cyan dye. The yellow main dye does not usually have an associated mask dye.

The photographic process is such that, as the quantity of cyan and magenta dyes are varied, the amount of yellow and orange mask dye varies in an inverse proportion. It is possible to combine the spectral characteristics of the main coloured dyes with their associated mask dyes to produce a set of three dye characteristics referred to as the Equivalent Dyes.[2]

These spectral characteristics contain regions of 'negative density' which are attributable to the operation of the masking dyes. A typical set of equivalent dyes is shown in Fig. 3.

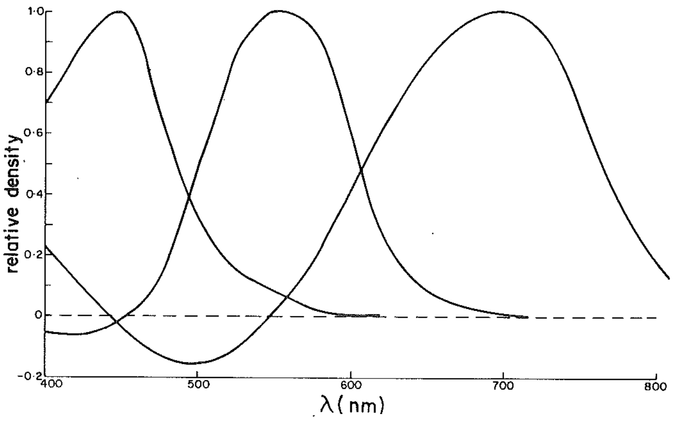

Fig. 3 - The equivalent dyes of a colour negative film

The masking coefficients may be found using these spectral characteristics together with grey-scale correction, as described previously for non-masked negative films.

4.6. Correction for film analysis errors

Since films are not designed with television reproduction in mind, the analysis of the film is not exactly that required to suit television phosphors. Electrical correction for non-ideal analysis has been in use for some time in television cameras in the form of a 3 x 3 matrix of the linear television signals relating to the light stimuli. It can be shown that, given reasonable camera analysis, the matrix is a major factor controlling the overall colorimetry. In telecine reproduction of film a linear matrix may also be used. However, the required signals (R_1, G_1 and B_1) occur only in the logarithmic or gamma-corrected form after masking correction for the unwanted dye cross coupling. It has been found that a matrix operating on the logarithmic signals produces very nearly as good a result as the linear matrix and, since a matrix already exists for the film dyes, the analysis correction matrix is usually combined with the dye-masking matrix to produce a single matrix for the whole correction process. The calculation of the analysis matrix involves utilising an optimisation computer programme which has been described[3] and will not be repeated in this report except to say that the matrix must be designed for use with logarithmic signals instead of linear ones.

5. The calculation of masking matrixes with the aid of a computer

Calculation of the masking matrices so far described becomes a lengthy process unless a computer is used. A considerable amount of arithmetic is involved since it is necessary to carry out calculations for each of a set of wavelengths spaced at ten nanometre intervals throughout the visible spectrum.

The operation of the computer calculation is best explained with reference to a flow diagram (Fig. 4).

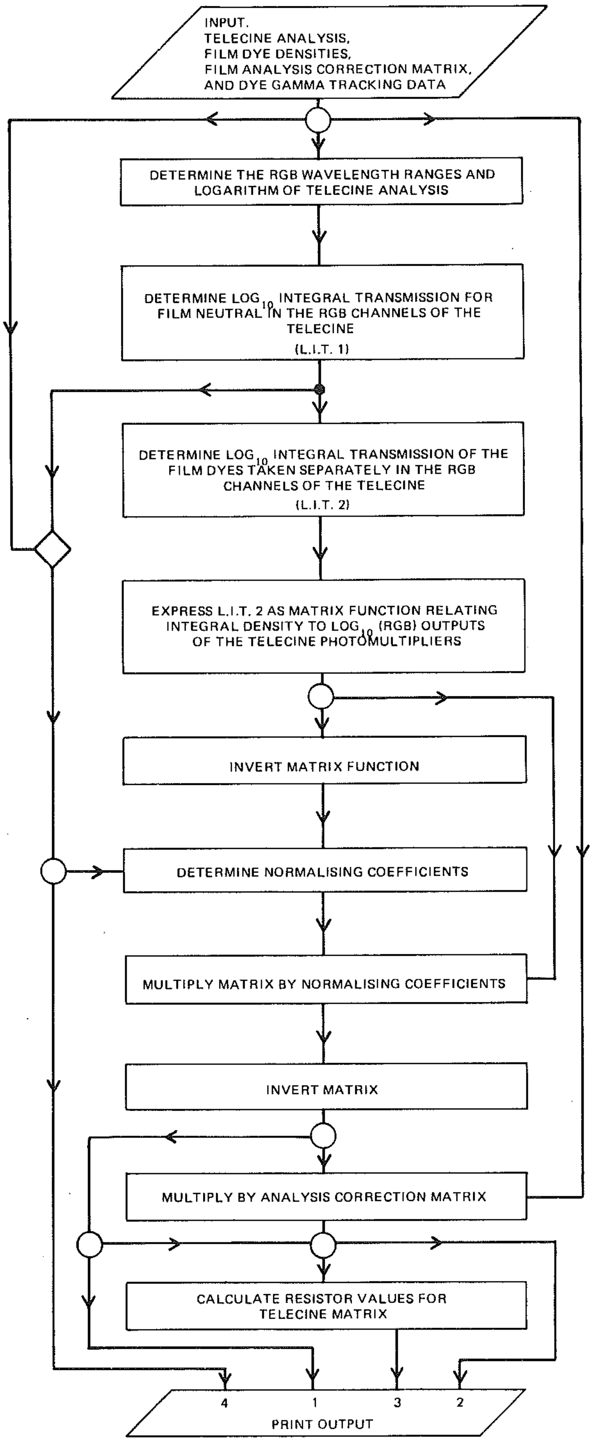
INPUT.
TELECINE ANALYSIS,
FILM DYE DENSITIES,
FILM ANALYSIS CORRECTION MATRIX,
AND DYE GAMMA TRACKING DATA
DETERMINE THE RGB WAVELENGTH RANGES AND LOGARITHM OF TELECINE ANALYSIS
DETERMINE LOG10 INTEGRAL TRANSMISSION FOR FILM NEUTRAL IN THE RGB CHANNELS OF THE TELECINE (L.I.T. 1)
DETERMINE LOG10 INTEGRAL TRANSMISSION OF THE FILM DYES TAKEN SEPARATELY IN THE RGB CHANNELS OF THE TELECINE (L.I.T. 2)
EXPRESS L.I.T. 2 AS MATRIX FUNCTION RELATING INTEGRAL DENSITY TO LOG10 (RGB) OUTPUTS OF THE TELECINE PHOTOMULTIPLIERS
INVERT MATRIX FUNCTION
DETERMINE NORMALISING COEFFICIENTS
MULTIPLY MATRIX BY NORMALISING COEFFICIENTS
INVERT MATRIX
MULTIPLY BY ANALYSIS CORRECTION MATRIX
CALCULATE RESISTOR VALUES FOR TELECINE MATRIX
4
1
3
2
PRINT OUTPUT

Fig. 4 - A computor programme flow diagram for the calculation of electronic masking

Output consists of:
(1) The matrix for film dyes
(2) The matrix for film dyes together with analysis correction
(3) Resistor values for the telecine matrix
(4) The film gammas when viewed by telecine before masking

5.1. Input data

The input data for the calculations consists of several parts, as listed below:

(1) Telecine analysis characteristics at ten nanometre intervals over the range 380 to 750 nm.

(2) The film-dye spectral-densities, if possible for an equivalent neutral density of 1·0, at each ten nanometre interval.

(3) A matrix, previously calculated by an optimisation process, which by operating upon the telecine signals produces a 'best fit' condition between the original film analysis and the television display phosphors.

(4) If required, the normalising coefficients for the film which have been determined by practical measurement. This is usually only required for negative colour films or where the individual dye densities which form an equivalent neutral density of 1·0 are not known.

5.2. Calculation

The first section of the programme calculates the telecine signals which are produced when a film with an equivalent neutral density of 1·0 is scanned. Since, for a density of 1·0, a signal representing 10% (transmission) would be expected, the ratio of the expected and calculated signal expressed in density form gives a normalising coefficient which is later used to modify the masking matrix to maintain accurate reproduction of neutral brightness levels. If the quantities of the separate dyes, which together form a neutral density of 1·0 are not known, then the normalising coefficients may be found, as described previously, from measurements of photomultiplier signals when a film grey-scale is scanned and these values substituted for the calculated values.

The telecine signal, expressed as a density, is the logarithm of the integral of the reciprocal of transmitted light over its sensitive wavelengths,

$$\text{i.e. } D_{(\text{telecine signal})} = \log_{10}\int_{\lambda_1}^{\lambda_2} \frac{1}{T(\lambda)}\,d\lambda = -\log_{10}\int_{\lambda_1}^{\lambda_2} T(\lambda)\,d\lambda$$

The abbreviation L.I.T. will be used to represent log integral transmission from this point in the description.

In order to produce a matrix function relating the film dyes to the telecine signals, the L.I.T. for each dye taken separately is now calculated. This enables the expression below to be used.

$$D_{(\text{telecine signal})} = \log_{10}\int_{\lambda_1}^{\lambda_2} T_c(\lambda)T_s(\lambda)\,d\lambda + \log_{10}\int_{\lambda_1}^{\lambda_2} T_m(\lambda)T_s(\lambda)\,d\lambda + \log_{10}\int_{\lambda_1}^{\lambda_2} T_y(\lambda)T_s(\lambda)\,d\lambda$$

where T_c, T_m, T_y are the film dyes transmission and T_s the telecine sensitivity.

Three such equations are calculated, one for each of the telecine signals and a matrix is derived.

$$\begin{bmatrix} \log R \\ \log G \\ \log B \end{bmatrix} = \mathrm{M} \begin{bmatrix} D_c \\ D_m \\ D_y \end{bmatrix}$$

The matrix is inverted and then the coefficients x_1, x_2, x_3 are calculated using the normalising coefficients calculated previously as data for log R, log G and log B.

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \mathrm{M}^{-1} \begin{bmatrix} \log R \\ \log G \\ \log B \end{bmatrix}$$

The values of $x_{1,2,3}$ are used to multiply the original matrix which is then inverted. This is now the mask matrix which will balance out all unwanted effects of dye absorptions in the electrical signals.

The matrix is now combined with the analysis matrix to give the final masking matrix and this is printed out as part of the results of the calculation.

The calculation is repeated for a range of equivalent neutral densities of dye scanned by the telecine from a density of 0·1 to 3·0. By comparing the values of these matrices for various densities the accuracy of the approximation used to establish the theory of the method (Section 4.2) may be checked. If large discrepancies occur it suggests the analysis bandwidths of the telecine are too wide.

Since the approximation used is most appropriate for low quantities of dye then the matrix for a density of 0·1 is the one used in practice.

6. Checking of the calculated masking system

A second computer programme has been written in which the film and telecine spectral characteristics together with the matrix calculated to remove the effects of unwanted absorptions of the film dyes were used as data. The programme set up a model telecine in which the quantity of one of the film dyes could be made to vary whilst maintaining constant density of the remaining two dyes. The telecine output signals were derived (a) for conditions of no masking matrix correction and then (b) for conditions including correction. Figs. 5, 6 and 7 show graphically the results obtained when one dye density is varied from 0·2 to 2·0 whilst maintaining the remaining dyes at density 1·0.

It can be seen that even with wide band analysis the masking matrix provides almost complete correction for the effects of unwanted absorptions by the film dyes.

It has been found, in practice, that variations in performance with various film stocks may be reduced to small proportions, the residual errors being due to internal dif-

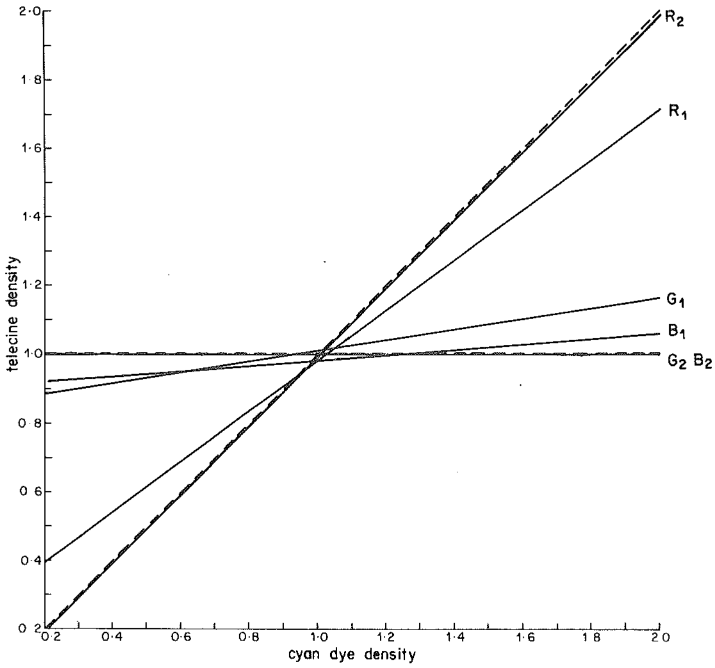

Fig. 5 - The effect of masking upon unwanted dye absorptions

The density of Cyan dye is varied from 0·2 to 2·0
The density of Magenta dye = 1·0
The density of Yellow dye = 1·0
$R_1G_1B_1$ are unmasked results
$R_2G_2B_2$ are masked results
------- Ideal system with no crosscouplings

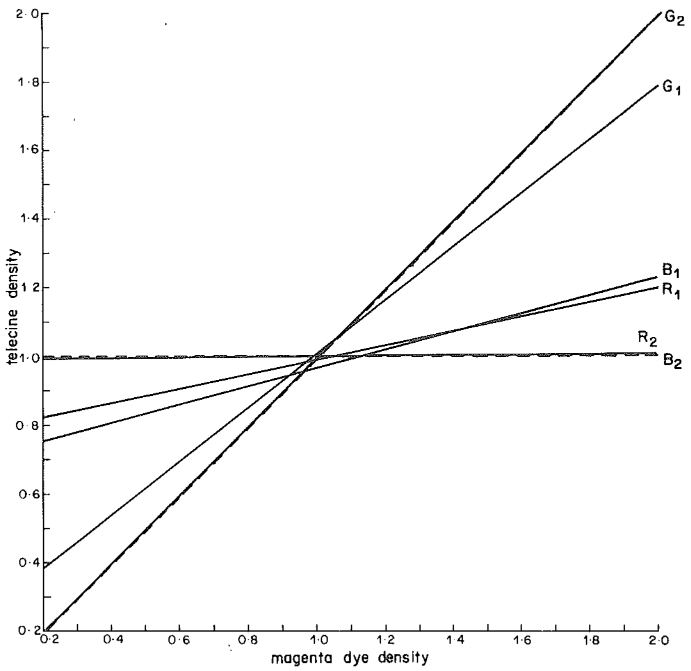

Fig. 6 - The effect of masking upon unwanted dye absorptions

The density of Magneta dye is varied from 0·2 to 2·0
The density of Yellow dye = 1·0
The density of Cyan dye = 1·0
$R_1G_1B_1$ are unmasked results
$R_2G_2B_2$ are masked results
------ Ideal system with no crosscouplings

ferences of film stocks as yet uncompensated for. Over ranges of luminance which do not suffer great distortion, the colour performance using positive print film is very similar to that obtained from negative film.

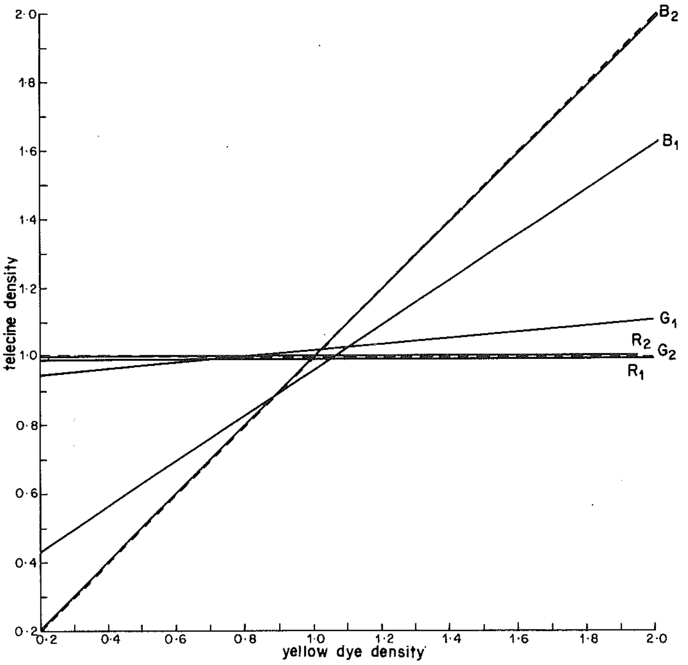

Fig. 7 - The effect of masking upon unwanted dye absorptions

The density of Yellow dye is varied from 0·2 to 2·0
The density of Cyan dye = 1·0
The density of Magenta dye = 1·0
$R_1G_1B_1$ are unmasked results
$R_2G_2B_2$ are masked results
------- Ideal system with no crosscouplings

7. Conclusions

The method of calculating masking matrices as described provides a reliable means of obtaining a high performance from a colour telecine. Using this method different telecine analysis characteristics may be used, yet the colour performance may be made the same. Indeed at one time, there were two different sets of analysis in use by the BBC Television Service, each with appropriate matrices, and yet nominally identical pictures were produced from a given film.

8. References

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